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DEVELOPMENT OF A TESTBED FOR INVESTIGATION OF ATM-BASED PACKET VIDEO CONCEPTS

Rensselaer Polytechnic Institute

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13. ABSTRACT (Maximum 200 words)

This report documents the accomplishments of a program to implement and utilize an ATM (Asynchronous Transfer Mode) testbed at Rensselaer Polytechnic Institute. The testbed is part of a variety of ongoing projects in the Center for Image Processing Research (CIPR). Two examples of projects employing the testbed are described in detail. The first is the development of innovative approaches to distributed distance learning using multimedia. The second is the realistic evaluation of promising approaches to the delivery of multimedia over ATM-based Broadband ISDN Networks.

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1 INTRODUCTION

The ATM Testbed (Figure 1) is housed in the Image Processing Laboratory, the primary research facility of the Center for Image Processing Research (CIPR). The testbed currently consists of four SPARC 10's with cameras and microphones linked by three networks: Ethernet, FDDI and ATM. The ATM network employs a Fore Systems, Inc., 8-port switch which was acquired under this effort. Together, the networks form a testbed which has been used in evaluating network speed, reliability, and error recovery as well as distance learning approaches. The lab is also linked by Ethernet (and in the future ATM) to the RPI backbone.

The testbed provides a useful structure with which to test a wide variety of approaches to important problems in multimedia. Two, which are described here, are the development of network-based multimedia education and a forward error-control (FEC) approach to minimizing the effects of packet loss in ATM networks.

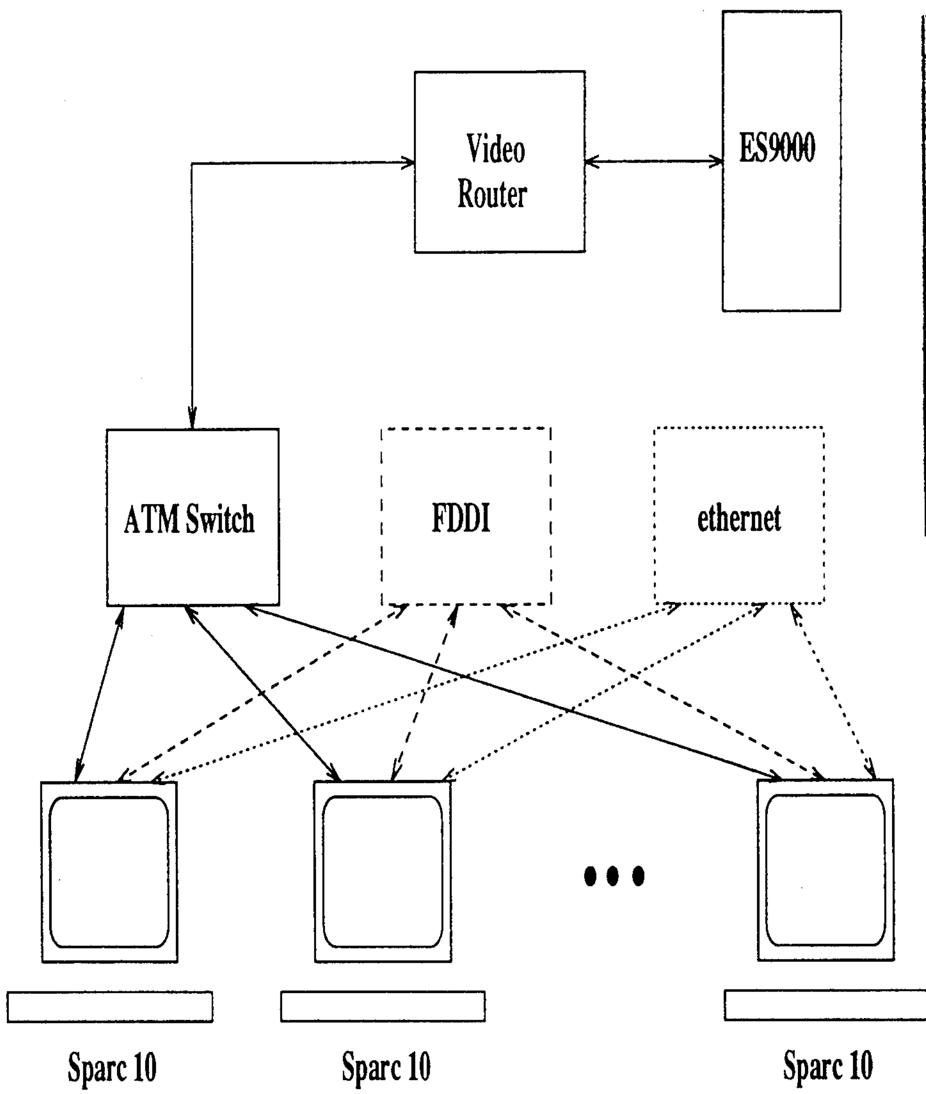

Figure 1: A Schematic of the CIPR Testbed Illustrating the Interconnection of SPARC 10's by Three Networks: Ethernet, FDDI and ATM.

2 NETWORK-BASED MULTIMEDIA EDUCATION

As described above, the CIPR ATM testbed consists of four SPARC 10's with cameras and microphones linked by three networks: Ethernet, FDDI and ATM. The testbed has allowed us to explore innovative approaches to the delivery of multimedia education.

The primary multimedia software tools which were employed to facilitate our networked multimedia distance learning are *Communique!* and *Mosaic. Communique!* is a commercial package, developed by Insoft, Inc., which allows a number of users to share a variety of applications including a common white board as well as voice and video. Mosaic is a flexible and freely available network-based multimedia interface which is easy to use and fast becoming a de facto standard.

Some of the key components of this work which are described below are

- Interactive distance learning and sharing of applications using *Communique!*.
- Hyperlinks to software packages.
- An interactive, multimedia education demo using Mosaic.

For more information, a demo and examples of distance learning sessions, see the CIPR Mosaic home page [7].

2.1 Video Conferencing and Interactive Distance Learning Using Communique!

Communique! is a video conferencing software package developed by Insoft which we have adapted for use in distributed distance learning. The significant features of *Communique!* are its ability to link many conference members by voice and video, allowing them to share drawing tools, notepads and a wide variety of applications software packages. To demonstrate some of our distance learning capabilities, we have composed a tour of our system, using snapshots of the software as a student would see it. This tour can be reached from the CIPR Mosaic home page [7].

The tour of an interactive distance learning session presents several scenarios. First of all, a student reviewing previous lectures can start a software "VCR" to display a pre-recorded lecture. The student is able to fast-forward, rewind and play the lecture at different speeds, or quit the lecture and resume at any time.

In all of the examples on the tour, a professor lectures and interacts with students. The professor can choose to view any of the students on his screen, dismissing or displaying their video windows when needed.

If the lecturer has any preprinted slides or images, he may display them on the students' screens by loading these files into a graphics transmission utility. A window containing the slide or graphics will appear above all other windows on the students' displays. The students are then free to move or dismiss the window once they have seen the material.

At any time during the session, the professor may send text or other files with a file transmission utility. Likewise, the professor may send raster files with the graphics transmission utility or choose to display them in a shared white board. When the image is loaded into a shared white board, the white board is automatically updated on all the students' screens. The professor may then edit the image or make notes on the image while discussing it. This white board may also be used just as an overhead or a blackboard would be in a standard classroom.

When short notes must be written or something stated is not understandable, the professor may write to all of the students using the notepad. The students are free to add notes to this notepad as well. To preserve anonymity in order to encourage student participation, replies do not have to be identified.

Finally, the professor may share software with all of the students. This can be simulation software such as the program Khoros, Mosaic or Matlab. This tool is especially useful because the students are able to watch the professor's mouse and keystrokes. At the same time, a student may run the software in another window and repeat the simulations. A particularly important use of this facility is the coordinated use of multimedia learning tools such as the Mosaic-based one described below.

2.2 Software Packages for Use in Distance Learning

Software simulation packages may be utilized in a variety of ways. First of all, code has been developed to link commercial software packages to Xmosaic so that students may run simulations during the course of a distance learning session.

An example of a software package which can be utilized is an in-house project of a subband coder. A student may generate subband-coded sequences on the fly and experiment with setting a variety of parameters. Again, a demonstration of this can be found via the CIPR Mosaic home page [7].

2.3 A Mosaic-Based Interactive Learning Tool for "Introduction to Computer-Communication Networks"

In this project we have developed as an explicit example of distance learning a demonstration of a network-based, multimedia learning tool for an introductory course in computer-communication networks (CCN's). This effort has two distinct and complementary goals. One is to develop pedagogic materials which allow modes of learning that cannot be achieved by formal lectures, class notes or books. The other is to explore the potential of communication networks as a vehicle for accessing vast amounts of diverse instructional material and educational information.

This course in computer-communication networks considers the problems and limitations associated with connecting computers by communication networks. Topics covered include protocols, interface design, queueing, the ISO OSI Reference model and network configuration.

Networks are very large and complex systems which interact in complex ways with time and space (geography). An interactive learning tool with flexible animation and simulation is particularly valuable in teaching networks courses.

The major features of this network-based, multimedia learning tool which have been demonstrated so far include:

(a) *Animated simulations of various networks covered in the course.* Animation allows a student to visualize the dynamics of a system. In a field such as networking, the interplay of time and space is critical, and a figure can only capture a snapshot. Since the interplay of time and space in networks is a major area of our research, we have been well-positioned to identify and implement these animations in a manner which most effectively illustrates these concepts.

Since we wanted these animated simulations to be easily developed or modified by the instructor, we used an approach that separates the details of the graphics involved in the visualization from the dynamics of the system being animated. This is done by using a graphics package called *Geomview* (built at the University of Minnesota) that has an easy-to-use interface to a simulation which is written in the C programming language. Events that change the animation are passed as messages from the simulation to the graphics package. This limits the sophistication required of the course developer.

In the demo, simulations of the ALOHA and Time Division Multiple Access techniques have been developed and animated to illustrate this approach. The animation allows the student to see packets moving between buffers at stations across the network, including packet collisions and the retransmission of packets that suffer collisions. The system dynamics are separately written in C and interface with Geomview. The animation itself is invoked and controlled from within Mosaic by the viewer of the document.

(b) *Hypertext document creation.* This uses the facilities already available within Mosaic to allow a student to jump across different parts of the course, into material for an advanced course, or to relevant information on the Internet (such as electronic copies of research papers referenced in the document).

Another feature of hypertext is its flexibility. Courses typically insist on a linear development of the subject. Hypertext gives the course developer the opportunity to allow a student to explore the course material in an appropriately customized order. For instance, Computer Science majors taking the CCN course might find it natural to begin their study at the Application Layer and work down through the network layers, while EE's might prefer to work their way up from the Physical Layer.

(c) *Individualized annotations.* Also being investigated are developing facilities within Mosaic that allow a student to make his own annotations to a page that he is reading without having to make a physical copy of the original document or having to modify the original one.

(d) *Queries to the instructor.* An additional facility we have developed allows queries that a student might have while he is reading the document to be submitted immediately to the instructor or TA from within the Mosaic environment. This may also be used as a way of submitting homeworks or answers to tests and quizzes – especially those that are computer-based.

(e) *Canned instructional video.* This tool also includes a demonstration of how video (e.g., of an instructor lecturing or explaining an individual topic) can be linked to particular points in the document.

(f) *Remote interaction using Communique!.* As described above, we have demonstrated the ability to invoke Xmosaic from within *Communique!*, in concert with *Communique!'s* other features such as audio and video conferencing and the ability to share applications like text.

white board, graphics and still images. In addition to using this approach in a distributed-classroom environment, it appears to be an effective way of holding "virtual office hours," in which remote students, both on and off campus, interact with the instructor.

2.4 Educational Impact

The primary course affected by this project is 35.468, "Introduction to Computer Communication Networks" (CCN). Two graduate-level courses in networking which will also be impacted, but to a lesser degree, are 35.667, "Local Computer Networks and Multiaccess Communication" (LCN), and 35.6961, "Introduction to Broadband Communication Networks" (BBN).

CCN has an enrollment of 40–50 seniors and grad students each Spring. LCN and BBN are offered in alternate Fall semesters and typically have enrollments of 15-20 graduate students. The vast majority of these students are in Electrical Engineering or in Computer and Systems Engineering. Recently we have broadened the scope of these courses, and will continue to do so, which we believe will lead to increased enrollment from outside ECSE, especially from Computer Science and the Decision Sciences and Engineering Systems Department.

This project has unusual potential for impacting the nature and direction of the development of multimedia education beyond the networking course area at RPI. In particular, the use of networking, through the Mosaic user interface, offers the potential for integrating a vast array of existing and future pedagogic tools and applications, independently of where they reside in the Internet. While it may be particularly interesting and appealing to employ such a network-based approach to a course on networking, virtually every aspect of this approach is applicable to any multimedia educational environment.

Mosaic is fast becoming a universal application on the Internet due to its power and simplicity. Our tool is accessible from any machine on the Internet as long as it has mosaic software, such as the freely available Xmosaic. This includes the campus-wide network of Unix workstations at RPI referred to as the Rensselaer Computing System (RCS). The caveat at this point is that the user must have the (freely available) Geomview package installed on their machine.

3 PACKET VIDEO OVER ATM

Packetized video is likely to be one of the most significant high-bandwidth users of ATM networks and a dominant component of the challenge to deliver multimedia. The transmission of variable bit-rate (VBR) video offers the potential promise of constant video quality but is generally accompanied by packet loss which significantly diminishes this potential. Our work in this area has focussed on generic solutions (applicable to a wide range of video coders) to the problem of packet loss for VBR video transmission in ATM networks. Though we limit our study to video transmission, this work extends to the transmission of other multimedia traffic as well.

The simplest way to recover from packet losses is through the use of *passive* error concealment schemes. An example of such a scheme would be to use the information from previously received frames to replace the regions missing in the current decoded frame. However, imperfectly recovered packets lead to error propagation in representative video compression algorithms, particularly those using motion compensation [1]. This is especially true under moderate-to-heavy losses during transmission of coded video containing scene changes or rapid motion. As a result, it would appear highly beneficial to use some form of *active* recovery scheme, such as forward error-control (FEC) coding, which offers the potential benefit of improved recovery in the event of packet loss and/or errors. Although the use of FEC does not guarantee lossless transmission, it provides a significant reduction in packet losses. The residual packet losses can then be reduced to the point where simple *passive* error concealment techniques are effective.

The conventional use of FEC for VBR video transmission applications has generally involved allocating additional bandwidth to accommodate the code redundancy introduced while maintaining a fixed specified video coding rate. We refer to this as an unthrottled source-coder/FEC system in contrast to the case where the video coding rate is reduced, or throttled, in order to accommodate the FEC bandwidth expansion. More specifically, the video coding rate is reduced so that, after the application of FEC, the total transmission rate is identical to the video coding rate of the unthrottled system. We refer to this as a throttled source-coder/FEC system.

If all the packets could be recovered in an unthrottled system, the reconstructed video quality would be identical to that provided by the same video coder operating at the specified rate in a lossless environment. By contrast, if all the packets are recovered in a throttled system there is a predictable performance disadvantage compared to the unthrottled system since the video coding rate has been reduced relative to that of the unthrottled case. On the other hand, since video is likely to be a dominant traffic type on ATM networks, the unthrottled approach, due to the associated bandwidth expansion, will further exacerbate congestion leading in turn to increased packet loss rates, especially under heavy load conditions. Indeed, at some point this can exceed the erasure correcting capability of the FEC resulting in significant and rapid degradation of the reconstructed video. The throttled system, on the other hand, does not lead to an increase in network congestion and, despite the reduced video coding rate, can deliver considerably improved performance over the unthrottled approach. This is a form of combined source-channel coding [3] where the source coding rate is traded to provide protection against packet losses while maintaining a fixed transmission bandwidth.

The performance of schemes using FEC is also related to the particular code used. Furthermore, due to channel coding overheads, it is desirable to minimize the amount of quality traded for channel coding operation while at the same time maximizing the protection achieved. Poorly chosen codes not only waste transmission bandwidth, but also provide little protection under congestion. As a result, we have developed a judicious code selection strategy, investigated its impact on performance and are actively engaged in studying techniques to improve the efficiency of FEC-based transport schemes.

FEC-based loss control is a very important component of an ATM Adaptation Layer (AAL). For example, the ATM Adaptation Layer, AAL 1, contains a proposed convergence sublayer to handle constant bit-rate (CBR) video which uses FEC as a means of protection against packet loss [5]. The same idea can be applied for transmission of VBR sources. Therefore the code application and selection strategy developed here is critical to the effective design of AAL interfaces for VBR video transmission. In the following subsections, we provide a more detailed description of this work. We begin with a brief description of the overall system.

3.1 System Description

Figure 2 provides a general block diagram of a video coding and prioritization scheme for transmission over a packet-switched network. Though the ideas presented here are applicable to

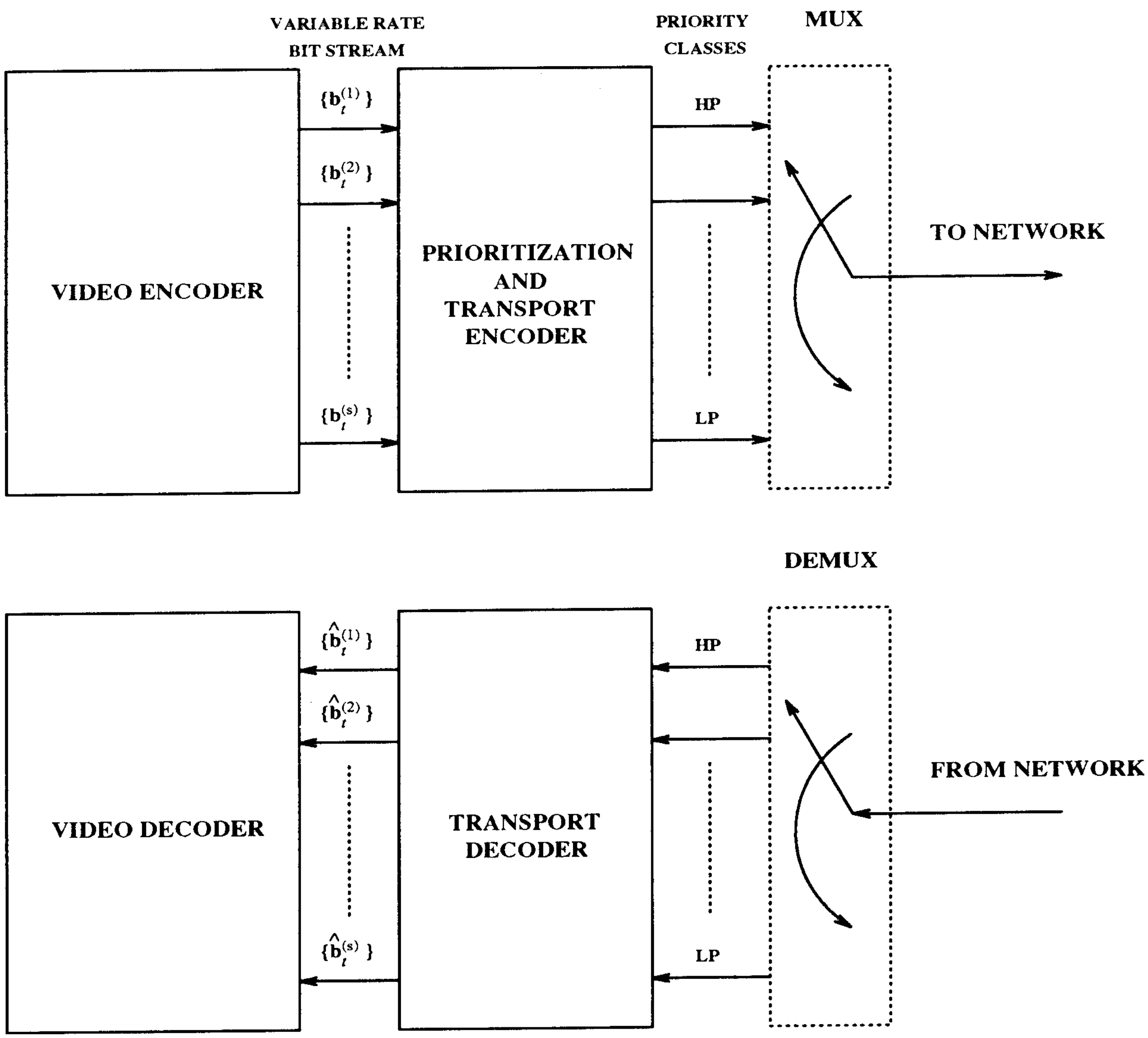

Figure 2: A Generic Block Diagram of a System for Video Transmission over a Packet-Switched Network.

arbitrary packet-switched networks, we focus on ATM. This diagram is generic in the sense that it is applicable to any chosen source coding scheme (e.g., a subband or a DCT-based system such as MPEG) or transport coding scheme (e.g., single or multiple priorities, with or without FEC). This work employs an entropy-constrained subband-based coding (ECSBC) scheme due to its excellent subjective quality and the fact that its multiresolution decomposition properties are well-suited to effective prioritization for heterogeneous networking environments. However, our recent experiments with the MPEG-2 coding scheme provide similar results. The output of the video coder is prioritized, packetized and transmitted over the network. Details of the ECSBC coding scheme can be found in [1] and [2].

3.2 FEC Codes and Their Application

In this section, we discuss the interlaced application of FEC codes to ATM and the FEC coding delays involved in this operation. Reed-Solomon (RS), Bose-Chaudhuri-Hocquenghem (BCH) and many other classes of codes can be used for FEC [4]. RS codes make use of the generated overheads efficiently and have attractive minimum distance properties. Accordingly, they can be used effectively for burst erasure recovery which will prove valuable in the face of correlated cell loss. Therefore, although our methodology extends easily to other codes as well, we focus on the use of RS codes.

FEC is applied through interlaced coding across packets by grouping the information bits in the packet into q-bit symbols. The technique used here is the same as the approach in earlier work. More specifically, for the application of the RS(N,K) code, K packets are converted into N packets through the application of an RS(N,K) code across each of the q-bit symbols in a packet. This operation would be performed prior to transmitting the packets over the network.

An important parameter then to be considered for practical operation is the FEC coding delay. This delay is defined to be the delay introduced by the interlacing operation. However, in [1] we have shown that for interactive applications the FEC delay is tolerable for practical operating rates. This is true for codes of small-to-moderate code length. For long codelengths the delay prevents their application except over selected operating rates.

3.3 Results and Discussion

The packet loss behavior is modeled as a two-step Markov chain in order to capture the correlated loss behavior. Two parameters, namely the steady state loss probability P_L and the one-step transition probability ρ_{LL} (which captures the correlation between losses) are required to specify the model parameters. In the first experiment to be described, we compare the performance of the throttled, unthrottled and unprotected scheme for the *Football* sequence which exhibits rapid motion. We base the choice of the parameters of the two-state Markov loss model on actual simulations of a multiplexer under different loads. Although the multiplexer is not a complete network, it provides some elementary idea of the performance that can be achieved. Results are illustrated in Fig. 3 where we plot the reconstructed SNR vs. the number of sources multiplexed in the high load region (i.e., a large number of sources) as the congestion is normally more severe in such cases. We use only a single priority structure in this example as the primary purpose is to demonstrate the superiority of the throttled approach without having to get into the network priority and buffer management issues. The multiplexer operating rate is 100 Mbps (FDDI speed) while the buffer size chosen is 500 packets. A value of 100 Mbps is chosen to represent a practical multiplexer operating speed yet maintaining a reasonable simulation time. As the figure indicates, with increasing load, there is as much as a 6 dB difference between the throttled and unthrottled scheme and up to a 4 dB difference between the throttled and unprotected scheme. This figure also confirms that the unthrottled scheme leads to poor performance under heavy loads due to the associated added congestion. In fact it behaves worse than the unprotected system. In particular, notice the substantial improvement in performance that can be achieved with the proper use of FEC.

Our next result emphasizes the need for a good code selection strategy. These results are particularly useful in the case of AAL interface design. Detailed descriptions of the code selection strategy can be found in [1]. Briefly, the code which maximizes the code rate K/N while satisfying constraints on the decoded loss probability $L_{threshold}$ and delay $D_{threshold}$ is chosen. This maximization is performed over all allowed RS code symbol sizes. Note that the code which maximizes K/N minimizes the throttling or in other words the quality sacrificed for the channel coding operation.

Figure 4 demonstrates the effectiveness of the resulting code selection policy. The overall transmission rate is 0.85 bits/pixel as it is sufficient to provide reasonable coded quality for this particular sequence. In the figure, the distortion is plotted as a function of code rate. Not surprisingly, with decreasing code rate, the performance improves up to a point because most losses are recovered by the code employed. At the same time, beyond a certain code rate, too much quality is sacrificed for the channel coding operation. As a result, the quality lost in channel coding is much more than that due to imperfect recovery. Also shown in the figure is the performance of the RS(128,124) code which has been proposed for the AAL 1 layer. The optimized code obtained according to the selection policy performs much better than the RS(128,124) code. One important conclusion that can be drawn from the figure is that as long as the code rate is properly chosen, a codelength of 63 is sufficient in providing good performance. This is particularly useful since it indicates that codes of relatively small codelength (the FEC decoding complexity depends on the codelength) are sufficient to yield good performance. Though the optimized code was selected here for a particular value of the Markov chain parameters, such an accurate description of the loss behavior in the network is seldom available. As a result, it is important to consider the behavior of the optimized codes when the Markov chain parameters differ from the design values so that the behavior of the network under temporary overloads is captured. This behavior is illustrated in the figure for two cases, one of which was selected with a 5 msec constraint on the FEC coding delay $D_{threshold}$ and the other a 20 msec constraint. The 5 msec constraint limits the number of available codes that meet the threshold on the loss. As a result, much lower code rates are required to achieve good performance. Even under mismatched operation, observe that the optimized codes perform very well indicating the robustness of the code selection strategy. The figure also depicts an information-theoretic upper bound developed in [1] on the performance. This bound was developed by modeling the packet loss channel as a special case of a *block interference* channel [6]. Notice that the optimized code is close to the information-theoretic bound on performance. To achieve performance much closer to the bound is possible but this would require extremely long codelengths, which would introduce intolerable delay into the system thus affecting its feasibility for real-time communication.

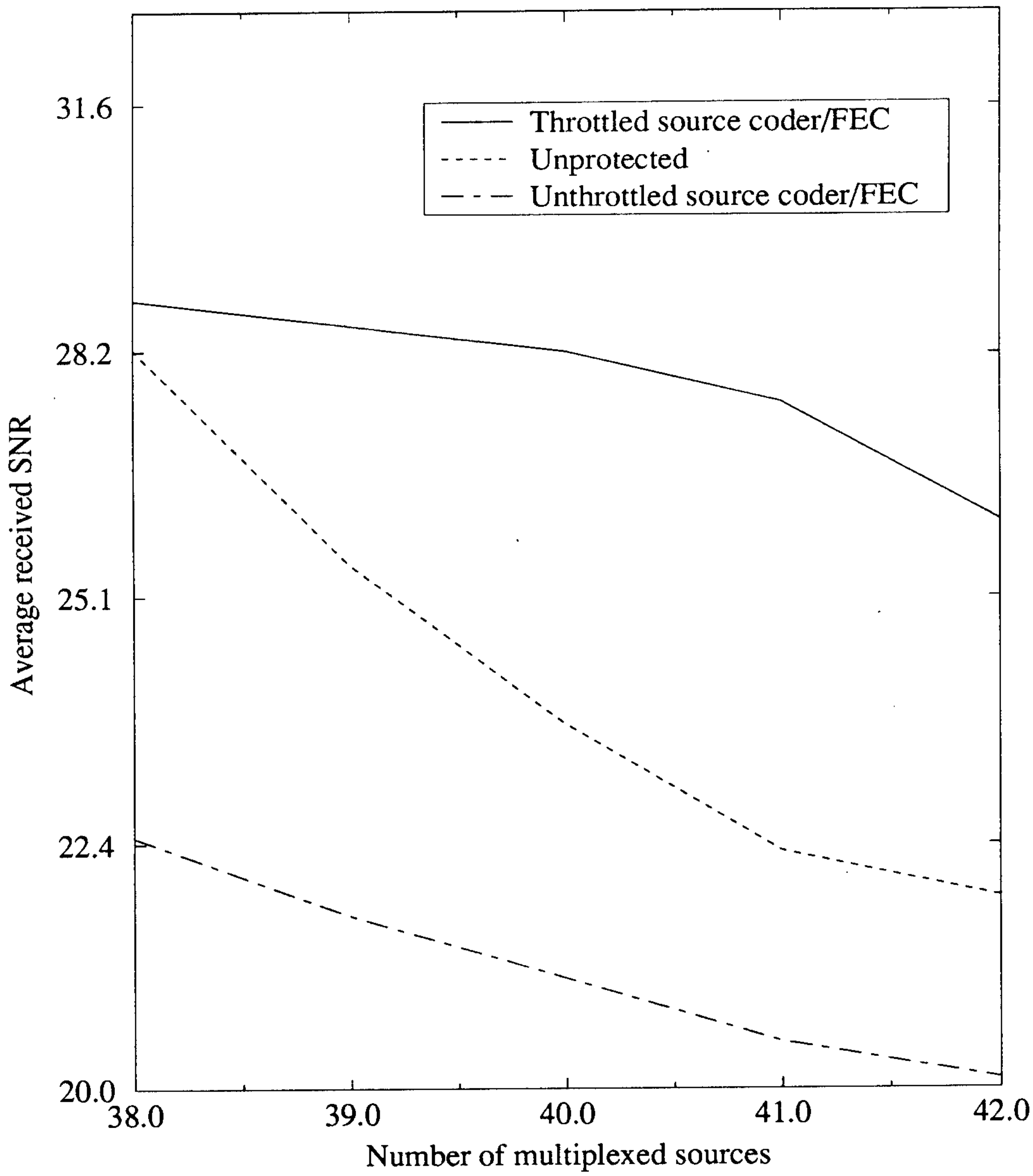

Figure 3: Comparison of the performance of the 3 schemes. Multiplexer speed is 100 Mbps, buffer size is 500 packets and source coder operating rate = 0.93 bits/pixel for the unthrottled and unprotected scheme while it is 0.80 bits/pixel for the throttled scheme. The RS(15,13) code is used.

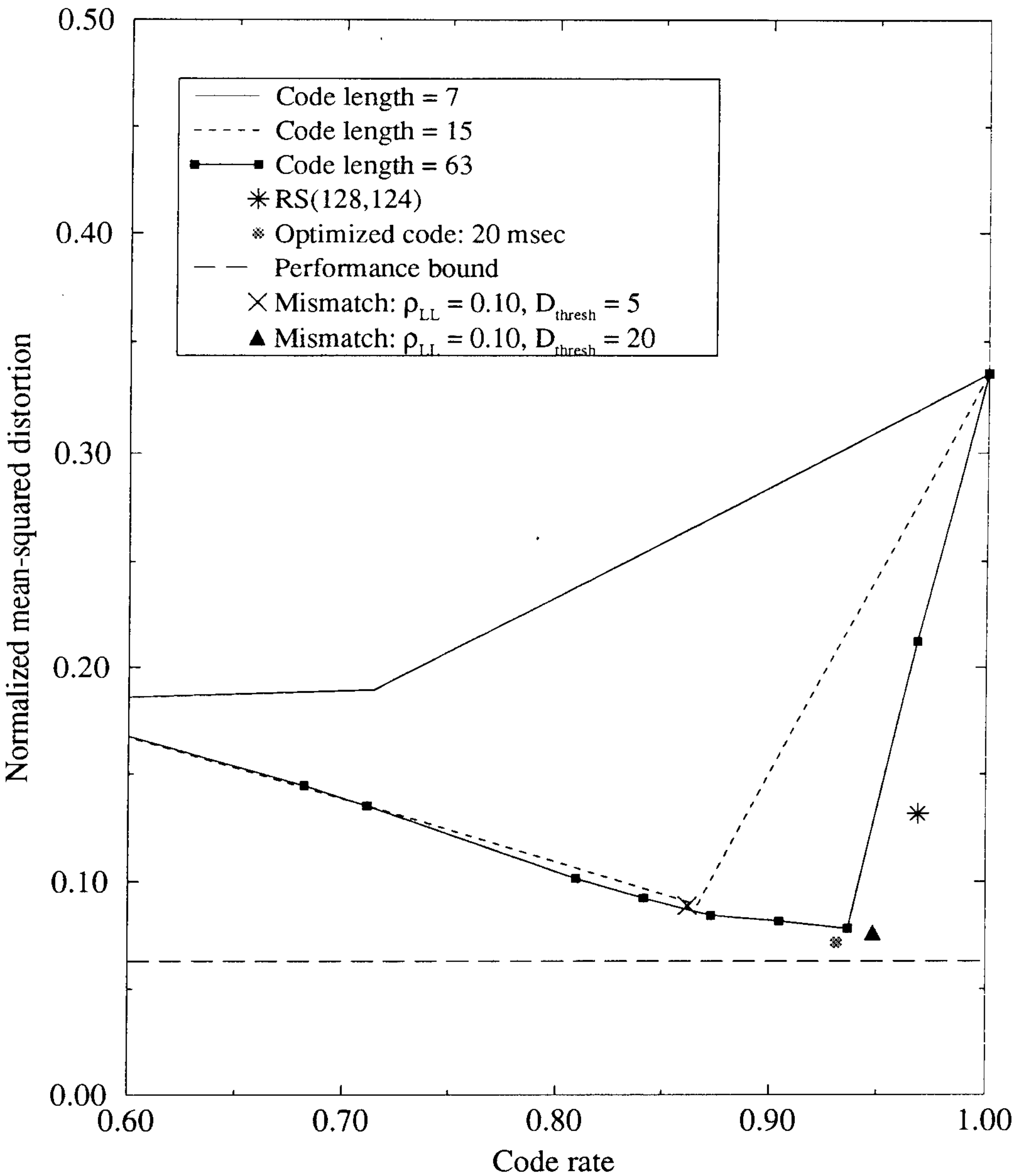

Figure 4: Performance of the code selection strategy. Loss probability $P_L = 1 \times 10^{-2}$ for both priority classes, $\rho_{LL} = 0.25$, sequence is the *Football* sequence, $N_f = 12$ and the overall average transmission rate is 0.85 bits/pixel.

4 Future Work

We have succeeded in developing an experimental ATM testbed for the investigation of ATM-based packet video concepts and in demonstrating the utilization of this testbed in two specific applications. The first application was in demonstrating, at least locally, the delivery of distributed distance learning concepts while the second application was as a research tool in theoretical investigation of FEC-based transport protocols. There remains considerably more useful work that can be done in exploiting and extending the capabilities of this testbed. This would include the following:

(a.) *Incorporation of a Video Server on the ATM Network.* One of the present deficiencies of the existing testbed is that there is no capability for storing and accessing large video sequences at frame rates and spatial resolutions which are useful in support of present and contemplated future applications, either distance learning demonstrations or research investigations. It would be of some interest then to acquire an appropriate video server to remove this deficiency. Two possibilities exist here: First, there is presently an IBM ES9000 mainframe on the Rensselaer campus which is ideally suited for use as a video server and, indeed, IBM is presently marketing this machine for this purpose. All that's required is to purchase a router, manufactured by CISCO, Inc., and an appropriate ATM interface to allow connection to the FORE System, Inc., switch. The second possibility would be to acquire a workstation-based video server utilizing RAID technology such as is presently marketed by several workstation vendors (e.g., SUN, HP, Silicon Graphics, etc.). In either case, the incorporation of a video server into the existing ATM testbed would significantly enhance its capabilities.

(b.) *Connection to External ATM Network.* At present, the ATM testbed is entirely local to the CIPR at Rensselaer. That is, we have no external connections to regional/national ATM networks. This severely limits the usefulness and interaction capabilities of the testbed. For example, should we acquire a video server, this would be available to users at remote locations and accessed over the regional/national ATM network. It would be of some interest then to provide such a connection to an external ATM network. Preliminary discussions have been held with NYNET representatives and we hope to eventually be connected to this regional ATM network.

(c.) *Additional Distance Learning Applications.* We have already described the use of *Communique!* and Xmosaic in the development of a multimedia version of the CCN course at Rensselaer intended for distributed distance learning. There are a number of improvements to this particular application that we would like to incorporate as well as several other courses we would like to encapsulate in a corresponding multimedia format. We are particularly interested in the development and demonstration of concepts for the remote delivery of such educational applications and would be most interested in working with Rome Laboratories on the development of other specific applications.

(d.) *Distributed Collaboration Applications.* The capabilities of the ATM testbed, particularly after augmentation with a video server and external ATM network connections, are useful not only for distributed distance learning, but also for demonstrating distributed collaborative work applications. We would be most interested in working with Rome Laboratories to identify, develop and demonstrate such applications.

(e.) *Packet-Video Transport Issues.* We have described in detail some of our work in developing FEC-based transport protocols for packet-video transmission over ATM networks. While we have obtained some preliminary results, considerably more work is required in this area. For example, much of our work has concentrated upon the use of wavelet-based subband video compression schemes. Much of our motivation for this concentration has been based upon the inherent multiresolution decomposition properties of subband coding schemes leading to a natural hierarchical prioritization approach. However, with the recent development and introduction of the DCT-based JPEG/MPEG standards, considerable attention has been focused upon building operational systems compliant to these standards and this activity is expected to accelerate with the present availability of VLSI chip sets for implementing JPEG/MPEG encoders/decoders. Unfortunately, the baseline, or mainprofile, version of JPEG/MPEG does not provide a multiresolution capability. Nevertheless, because of the increasing interest in JPEG/MPEG compliant systems, it's of some interest to invesetigate, develop and demonstrate ATM transport protocols for these compression schemes as well. We have some interest in studying the transport issues associated with use of JPEG/MPEG and, in particular, using them as a benchmark for assessing the relative performance/complexity tradeoffs compared to other compression approaches, such as subband coding.

(f.) *Use of Programmable Video Compression/Decompression Boards.* The existing ATM testbed utilizes JPEG compression/ decompression boards. As MPEG compression/decompression boards become available at reasonable prices, we would be interested in upgrading to MPEG (specifically MPEG-2) compression/decompression boards. However, this would not allow us to do real-time experiments and/or demonstrations using other compression/decompression schemes, such as subband coding. Since the multiresolution capabilities of subband coding approaches provide attractive system features, we are particularly interested in the ability to do real-time experiments and/or demonstrations using subband coding. This can be accomplished using programmable video compression/decompression boards which allow changing the compression/decompression algorithm under software control. This may be accomplished using the recently introduced TI video signal processing (VSP) chips. As a result, we have some interest in acquiring development boards and systems, using the TI VSP chips, and developing multi-purpose programmable video compression/decompression boards. This would considerably enhance the existing capabilities of the ATM testbed.

(g.) *Buffer Management for Video in ATM Networks.* In current work, we are developing an optimal buffer management scheme for multimedia traffic on ATM networks. These results use Markov decision theory and are theoretically superior to previous results in that the control depends on the state of the sources and not just the current buffer fill. We have demonstrated using both broadcast and conversational voice, that our approach leads to effective practical schemes (traces of our emulations can be found using Mosaic at http://networks.ecse.rpi.edu/audio.html). In future work, we plan to evaluate the effectiveness of our approach using video over ATM.

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